REVIEW OF CURRENT LITERATURE AND RESEARCH ON GAS SUPERSATURATION AND GAS BUBBLE TRAUMA

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INTRODUCTION

Over the past few years, there has been growing interest in the effects of chronic gas supersaturation on aquatic animals. This interest has been due primarily to heavy mortality of salmonid species under hatchery conditions. Extensive examination of affected animals has failed to consistently identify pathogenic organisms. Water quality sampling has shown that chronic levels of gas supersaturation are commonly present during a significant period of the year. Water quality criteria for gas supersaturation were formulated to protect migrating salmon and trout that experience high levels of gas supersaturation for relatively short periods of time. Small marine fish larvae are significantly more sensitive to gas supersaturation than salmonids. Present water quality criteria for gas supersaturation are not adequate for the. protection of either salmonids under chronic exposure or marine fish larvae, especially in aquaria or hatcheries.

The purpose of this report is to present recently published information and on-going research on the various areas of gas supersaturation. Much information in this field is published as agency reports with limited circulation and as a result may not be readily accessible to many people. To increase communication between interested parties in the field of gas supersaturation research and control, addresses and telephone numbers of all people responding to the questionnaire are included.This report was funded in part by the Bonneville Power Administration, U. S, Departmentof Energy and the Bioengineering Section of the American Fisheries Society. As this report will be updated in the future, researchers are encouraged to send copies of articles and reports to the senior author, especially limited-circulation reports that will not published or reviewed.

Additional copies of this report can be obtained from **Bonneville** Power **Administration (PJS), P.O. Box 3621, Portland, OR. 97208, USA**

NOMENCLATURE

The following abbreviations and symbols are used in this publication:

BP — Barometric pressure (mm Hg)

C* — Equilbrium concentration of dissolved oxygen in air at local temperature and pressure ‘(mg/l)

DO — Dissolved oxygen (mg/l)

GBT — Gas bubble trauma (gas bubble disease)

N_2(%) — Percent saturation of nitrogen gas. Also includes argon, carbon dioxide, and any other inert gases present.

O_2(0/0) — Percent saturation of oxygen gas

N_2/O_2 — Ratio of the partial pressure of (nitrogen + argon) : oxygen (unitless)

P_w — Vapor pressure of water (mm Hg)

TGP(%) — Total gas pressure in water expressed as a percent of local barometric pressure (%)

β — Bunsen coefficient of oxygen gas (l/(l.atm)

AP — Differential gas ‘pressure between totai gas pressure and the local barometric pressure (mm Hg)

The following relationships exist between the various gas supersaturation parameters:

$$\mathrm{TGP}(\%) = \left[\frac{BP + \Delta P}{BP}\right] 100 \qquad (1)$$

$$\mathrm{N2}(\%) = \left|\frac{BP + \Delta P - \dfrac{DO}{\beta}\,0.5318 - P_W}{0.7902\,(BP - P_W)}\right| 100 \qquad (2)$$

$$O2(\%) = \left[\frac{DO}{C^*}\right]100 \qquad (3)$$

$$N_2/O_2 = \frac{BP + \Delta P - \dfrac{DO}{\beta}0.5318 - P_w}{\dfrac{DO}{\beta}0.5318} \qquad (4)$$

and

$$TGP(\%) = 0.2094\left[O_2(\%)\right] + 0.7902\left[N_2(\%)\right] \qquad (5)$$

$$\Delta P = 0.20946\left[\frac{O_2(\%)}{100} - 1\right]\left[BP - Pw\right] + 0.7902\left[\frac{N_2(\%)}{100} - 1\right]\left[BP - Pw\right] \qquad (6)$$

$$\Delta P = \frac{DO}{\beta}(0.5318)(1 + N_2/O_2) - (BP - P_w) \qquad (7)$$

Some researchers compute TGP(%) and N_2(%) in a slightly different manner, depending primarily on inclusion (or exclusion) of the water vapor term. These differences are not significant at high ΔPs, but are critical at ΔPs less than 40 - 60 mm Hg, especially under warmwater conditions when the vapor pressure of water may be as high as 30 mm Hg. Additional information the computation and reporting of dissolved gas level is presented in **Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure. Colt, J. 1984, Special Publication No. 14, American Fisheries Society, Bethesda, Maryland.**

CURRENT LITERATURE

This section contains current literature on gas supersaturation and gas bubble trauma after 1980. Literature prior to this date is presented by Don Weitkamp and Max Katz (Transactions of the American Fisheries Society, 109:659-702, 1980). A number of pre-1980 articles are included in this publication if omitted by Weitkamp and Katz. Interpretation of data and results by reviewers is enclosed in square brackets (i..e. [ ]) to distinguish it from the author's conclusions. In order to present the most current literature, a number of articles either "in press", "submitted for publication", or "in preparation", have been included, It may be necessary to contact the author for additional publication information .

BUBBLE FORMATION

Epstein, P.S. and M. S. Plessat. 1950. On the stability of gas bubbles in liquid-gas solutions. J. Chem. Phys., 18:1505-1509.

A mathematical description of the stability of bubbles in liquids and the factors affecting growth and collapse.

Fidler, L. E. 1984. A study of biophysical phenomena associated with gas bubble trauma in fishes, Penny Applied Science., Ltd,, Box 337, Valemount, BC VOC 220. Contractors report to the Department of Fisheries and Oceans, Salemonid Enhancement Program, Vancouver, BC.

The derivation and analysis of equations governing the growth of bubbles in the vascular systems of fish produced mathematical descriptions of the thresholds for bubble growth as a function of the following parameters: (1) total gas pressure, (2) temperature, (3) oxygen to nitrogen ratio, (4) hydrostatic and barometric pressures, (5) oxygen uptake ratio across the gill membrane, (6) vascular system pressure, and (7) nucleation site radius, Within the known ranges of vascular system pressure and gill oxygen uptake ratio for salmonids, and physically realizable nucleation site radii, the mathematical relationships predict thresholds well within the range of those reported in the literature. Better definition of nuculeation site radius and its relationship to fish activity will provide an analysts tool capable of more detailed description of bubble growth thresholds.

A similar analysis applied to the swim bladders of physostome fish yield a relationship for overinflation thresholds. The mathematical expresstons involved the same parameters as those for vascular system bubble growth except for nucleation site radius and vascular system pressure which are not involved in the swim bladder inflation process.

Fox, F, E. and K, F. Herzfeld. 1954. Gas bubbles with organic skin as cavitation nuclei. J. Acoust. Soc. Am., 26:984-989,

A description of gas nuclei in liquids and the manner in which contaminants are concentrated at the liquid gas interface to form skins or shells which act as a stabilizing mechanism for nuclei.

Harvey, E. N,, D. K. Barnes, W, D. McElroy, A. H, Whiteley, D. C. Pease, and K. W. Cooper. 1944. Bubble formation in animals. J. Cell. Comp. Physiol., 24:1-24.

A *careful experimental examination of bubble growth in animals subjected to decompression. Excellent dtscussion of the role of nucleation* sites and the physiological factors which effect *their* activation *into growing bubbles, Excellent photographs of bubbles in tissue, vascular systems, and organs.*

Hemmingsen, B, B. 1986. Promotion of gas bubble formation by ingested nuclei in the ciliate, Tetruhymena pyruormis. Cell Biophysics, 8: 189-200.

Cell of the ciliate Tetrahymena pyriformis were suspended with carmine or graphite particles or with Halobacterium gas vesicles, all of which promote bubble formation fn aqueous *suspensions when tested with nitrogen gas supersaturation, All three particles were ingested, but only the gas vesicles promoted intracellular gas bubble* formation *if the cells containing them were nitrogen or* methane *saturated in a slow stepwise fashion* prior to *rapid decompression, The inability* of the ingested carmine, *graphite, and collapsed gas vesicles to induce intracellular gas bubble formation suggests that the phagocytic **process** somehow altered them.*

Hemmingsen, B. B., N. A. Steinberg, and E. A, Hemmingsen. 1985. Intracellular gas supersaturation tolerances of erythrocytes and research ghosts. Biophys. J,, 47:491-496.

Intact mammalian, avian, *and amphibian erythocytes were saturated with up to 300 atm nitrogen or argon and rapidly decompressed, No evidence of intracellular gas bubbles* was *found: all* **or** *most of the cells remained intact and 'little or no hemoglobin escaped. The absence of bubbles may indicate that much of the internal **water** does not have the same nucleation properties as external water.*

Hlastala, M,P. and L. E, Fahri. 1973. Absorption of gas bubbles in flowing blood. J. Appl. Physiol., 35:311-316.

Description of the stability of nucleation sites and bubbles in blood and some of thefactors which may affect this stability.

Hsieh, D. Y. 1965. Some analytical aspects of bubble dynamics, J. Basic Eng, Trans. ASME, 87:991-1005.

A detailed derivation of the equations which govern the dynamics of bubbles in almost any enviromen t. Highly mathematical, but extremely detaited in the derivation and equation solutions.

McDonough, P. M. and E. A. Hemmingsen. 1985. Swimming movement initiate bubble formation in fish decompressed from elevated gas pressures. Comp. Biochem. Physiol., 81A:209-2 12.

Anesthesia reduces bubble formation in decompressed fish. This suggests that swimming movements are involved in the bubble initiation process. The most likely process for bubble formation is tribonecteation - nucleation at the points of rubbing contact between solid structures. This work does not support the hypothesis that bubbles arise in fish from preformed gaseous nuclei.

Philp, B., M. J. Inwood, and B. A. Warren. 1972. Interactions between gas bubbles and components of the blood: implications in decompression sickness, Aerospaee Medicine, 43:946-953.

An experimental examination of bubbles and nuclei in blood and the role blood components play in forming skins or shells arounds nucleation sites. Excellent micro-photographs of nucleation sites with organic skins.

Yount, D. E. 1979. Application of a bubble formation model to decompression sickness in rats and humans. Aviation, Space and Environ. Medicine, 50:44-50.

A mathematical model of nucleation site stability and bubble growth and how it would apply to decompression of rats and humans,

GAS BUBBLE TRAUMA

Fish

Alderdice, D, F and J, 0. T. Jensen, 1986, An explanation for the high resistance of incubating salmonid eggs to atmospheric gas supersaturation of water. Aquaculture, 49:85-88.

The increased resistance of salmonid eggs to gas supersaturation is due because the pressure inside the eggs is higher than the barometric pressure.

Bagarinao, T. and P. Kungvanki.. 1986. An incidence of swimbladder stress syndrome in hatchery-reared sea bass (Lated ***calcarifer)*** larvae. Aquaculture, 51:181-188..

Over-inflation of the swim bladder (swimbladder stress syndrome) resulted in floating fish and heavy mortality. The exact cause *of the problem was not idenified.*

[No information on dissolved gas levels was presented]

Bouck, G. R. and R. E. King. 1983. Tolerance to gas supersaturation in fresh water and sea water by steelhead trout, salmo *gairdneri* Richardson. J. Fish Biol., 23:293-300.

Mean time to mortaltty was not significantly different between fish held in fresh water and sea water, but *there* was noticeable trends *for* longer survival in fresh ***water.***

Bouck, G. R. and R. E. King. In Press, Effects of fasting and vitamin C on tolerance to air supersaturated water by rainbow trout, Can. J. Fish. Aquat, Sci.

Fasting decreased the tolerance of rainbow trout to GBT. Diets with too much or too little vitamin C may decrease the tolerance of rainbow trout to GBT.

Bowser, P. R., R, Toal, H, R, Robinette, and M. W. Brunson. 1983. Coelomic distention in channel catfish fingerlings. Prog. Fish-Cult., 45:208-209.

Exposure of fingerling channel catfish to gas supersaturation resulted in abdominal distention presumably due to accumulation of intra-abdominal gas.

Colt, J,, K. Orwicz, and D, Brooks. 1985. Impact of gas supersaturation on the growth of juvenile channel catfish, Ictulurus punctutus. Aquaculture, 50:‘153-160.

Exposure of juvenile channel catfish to levels of gas supersaturation that resulted in 58 % mortality had no effect on the growth of the surviving fish, The basis for this response is unclear at this time.

Cornacchia, J. W. and J. E. Colt. 1984. The effects of dissolved gas supersaturation on larval striped bass, *Morone saxutilis* (Walhaum). J. Fish Dis., 7: 15-27.

Clinical signs of gas bubble trauma were observed in 10 day old larval striped bass at ΔPs as low as 22 mm Hg, Older fish were less sensitive. GBT resulted in over-inflation of the swtmbtadder and accumulation of gas in the gut. Commonly, the larvae floated belly-up at the surface,

Feathers, M. G, and A. E. Knable. 1983. Effects of depressurization upon largemouth bass, North Am. J. Fish. Man., 3:86-90.

Depressurization can result tn over-inflation of the swimbladder and bubbles in the blood. Significant mortality can result if fish are caught in water 18 m or deeper,

Gray, R. H., T. L Page, M, G. Saroglia. 1983. Behavioral response of carp, Cyprlnus *carpio,* and black bullhead, *Ictalurus melus,* for Italy to gas supersaturated water. Environ. Biol. Fish,, 8: 163-167.

Neither carp or black bullheads avoided gas supersaturatfon near the 96-h LC50. The fish eventually avoided a TGP of 146 % after clinical signs of GBT had developed

Gray, R. H,, T, L Page, M. G. Saroglia, and P. Bronzi, 1982. Comparative tolerance to gas supersaturation of carp, *Cyprinus carpio,* and black bullhead, *Ictulurus* melas, from the U.S.A. and Italy. J. Fish. Biol., 20:223-227.

The carp and black bullheads from Italy were more susceptible to GBT than published data-for the same species from the Columbia River (US).

Gray, R. H., T, L. Page, M, G. Saroglia and V. Festa, 1983. Tolerance of carp *Cyprinus* carpio and black bullhead Ictalurus melas to gas-supersaturated water under lotic and lentic conditions. Environ, Poll. (Series A), 30:125-133.

Under 133% TGP, both carp and black bullheads were more susceptible to GBT when forced to swim. Above 133%, TGP, carp were more suscepiible under non-forced conditons.

Gray, R. H,, M. F. Saroglia, and G. Scarano. 1985. Comparative tolerance to gas supersaturated water of two marine fishes, *Dicentrurchus labrax* and Mugil *cephdus.*, Aquaculture, 48.:83-89.

The 96-h LC50 for post-larvae of the two species were similar: 127.2% for sea bass and 129.4% for striped mullet. For both species, finerlings were less tolerant of supersaturation than were post-larvae.

Hettler, W, F. 1970. Rearing larvae of yellow menhaden, *Breuoortia smithi.* Copeia, 1970:775-776.

GBT was a problem with the rearing of yellow menhaden.

[The source of the gas supersaturation was not identified]

Hnath, J. G., H, Westers, and H. G. Ketola. 1986. The effects of nitrogen gas supersaturation on the development of eye lesions in coho salmon, and possible mediating effects of a test diet.

In a laboratoy experiment, coho salmon eggs were incubated, hatched, and reared at total gas levels of 100, 102, and 106%. Each of 4 diets were fed at each gas level from fry to smoltification. The 4 diets were the Atlantic salmon,diet ASD2-30, ASD2-30 with 10% dried liver, Biodiet starter followed by OMP, and Bfodfet alone, Neither diet nor level of gas had a significant influence of the overall incidence of cataracts or eye lesions. Both diet and gas level had a significant effect on growth and mortality.

In hatchery tests, an experimental diet (T-2) reduced the incidence of cornea1 lesions and cataracts when compared to the OMP diet,

Jensen, J. 0. T. In Press. Combined effects of excess total gas pressure and dissolved oxygen levels on steelhead trout (Salmo *gairdneri)* eggs, alevins, and fry. Can. Tech. Rep. Fish. Aquat. Sci.

Steelhead eggs, alevins, and *fry* were exposed to combinations *of gas* supersaturation *(102 -111% TGPI and dissolved oxygen (48 - 98 % of saturation,) at 10 C, A small percent of fry exposed to 111% TGP and 48 % oxygen developed over-inflated swim bladders, After 21 days offeeding, fry size was not significantly correlated with either oxygen or TGP.*

Jensen, J. 0. T., J. Schnute, and D. F. Alderdice. In Press. Assessing salmonid response to gas supersaturation with a new multivariate dose-response model. Can. J. Fish. Aquat. Sci., 43.

Based on a general multivariate dose-response model, the 'safe' levels of TGP range from 103.8 to 1148% depending on associated factor levels of water depth and fish size.

Jensen, J. 0. T., A. N. Halley, and J, Schnute. 1985. Literature data on salmonid response to gas supersaturation and ancillary factors. Can. Data Report Fish. Aquat. Sci, No. 501.

Compilation of published fnformatfon on lethal response of salmonids to gas supersaturation as a function of *species, length, depth, time, TGP, and oxygen levels.*

Jensen, J. 0. T. 1980. Effects of total. gas pressure, temperature and total. water hardness on steelhead eggs, and alevins. A progress report. Proc. 31 st Northwest Fish Culture Conference, Courtenay, British Columbia, pp. 15-22.

The effecis of total gas pressure, temperature, and hardness on the incidence of white spot disease in steelhead eggs and alevins was Investigated. Over the range of values tested (gas pressure:1 02, 106, and 1 I 0%; temperature 8, 10, and 12 C: and hardness: 10 and 100 mgll @ $CaCO_3$) white spot disease was not observed. Increased mortality was observed at 110% TGP, 12 C, and 10 mg/l hardness. These mortalities were due to severe growth deformities of the operoulum which resultedjiom large bubbles that formed and enlarged in the alevins' mouth cavities shortly after hatching.

Johnson, D. W, and I. Katavic, 1984. Mortality, growth and swim bladder stress syndrome of sea bass *(Dicentrurchus Labrax)* larvae under varied environmental conditions. Aquaculture, 38:67-78.

Swim bladder stress syndrome (SEES) was thought to be due *to environmental stresses other than* gas supersaturation.

[No information on dfssolved gas levels or measurement techniques were provided]

Katavic, I,, N. C. Parker, and G. T. Klar, M'S, Effects of dissolved gas supersaturation on larval striped bass *(Morone saxatilis* Walbaum).

Studies were conducted to evaluate the response of *5-day* old *strfped bass to dissolved gas supersaturation. Sfgns* of *gas bubble disease were evident after 8 days of exposure to* 120, 130, and *14.0 % total gas pressure. Mortality increased as total gas pressure increased, Large dir embolf lodged in the peritoneal cavity fnterferred with equilibrium and forced larvae to swim at the* surface. *Larval* growth *was sfgnficantly reduced at 130 and 140% TGP. Supersaturation. consistently increased the* incidence *of intestinal bubbles and the cross sectional area of the swimbladder.*

Katavic, I. and N. C, Parker, MS. Effects of dissolved gas supersaturation on subadult striped bass *(Morone* saxatilis Walbaum).

In preparation,

Kolbeinshavn, A. and J. C. Wallace, 1985. Observations on swim bladder stress syndrome in arctic charr *(Salvelinus alpinus),* induced by inadequate water depth. Aquaculture, 36:259-261,

Increasing the water depth from 12 cm to *37 cm significantly decreased the incidence of over-inflated swfm bladders (Swim bladder stress syndrome).*

Kraul, S. 1983. Results and hypotheses for the propagation of the grey mullet, *Mugil cephalus* L. Aquaculture, 30:273"284.

Photosynthetic production of oxygen by algae in 'greenwater" culture may result in GBT in larval mullet. Clinical signs included accumulation of gas in the gut *and positively buoyant fish.*

Kulshrestha, A. K. and P. K. Mandal. 1982. Pathology of gas bubble disease in two air-breathing catfish (Clarias *batrachus* Linn, and *Heteropneustes fossilis* Bloch.), Aquaculture, 27: 13-17.

Description of the histopathology of high levels of gas supersaturation in two species of catfsh.

Lund, M. and T. G. Heggberget. 1985. Avoidance response of two-year-old rainbow trout, Salmo *gairdneri* Richardson, to air-supersaturated water:hydrostatic compensation. J. Fish. Biol., 26: 193-200.

No consistent vertical avoidance response was observed in rainbow trout exposed to 115 to 125% TGP. Increasing water depth will decrease mortality due to availability of greater range of water depths.

Mansueti, R. 1958. Eggs, larvae and young of the striped bass, *Roccus saxatilis.* Contribution No. 112, Chesapeake' Biological Laboratory, Solomons, Maryland;

Early description of GBT in larval striped bass.

Peterson, H. 1971. Smolt rearing methods, equipment and techniques used successfully in Sweden. In Atlantic Salmon Workshop, W. M. Carter (editor), International Atlantic Salmon Foundation, Frederiction, Nova Scotia, Canada.

TGPs in the range of 102 - 105 % resulted in the formation of small bubbles in the top of the mouth cavity and hfgh mortality 6 - 8 weeks later when the fish start to feed.

Shrimpton, J. M. 1985, Response of Coho salmon *(Oncorhynchus kisutch)* to different levels of gas supersaturation. B,S. Thesis, Department of Biology, University of Victoria, British Columbia, Canada.

Below 111% TGP, coho salmon increased their mean depth to compensate for increase gas supersaturation. Above 111% TGP, the fish no longer remained below the compensation depth.

Thorn, MT. C., C. Lessman, and R. Glazer, 1978. Some effects of controlled levels of dissolved gas supersaturation on selected salmonids and other fishes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries Investigational Report No. 347,

Based on mortality, lake trout appeared to more tolerate of gas supersaturation than brook, brown, and rainbow trout. *However, they showed the* highest incidence *of* eye damage. After a *month* of *exposure to* 113 % *TGP,* 20% of the lake **trout** *fingerlings showed* eye hemorrhaging and 4 % *had cataracts.*

Wright, P. B. and W. E. McLean. 1985. The effects of aeration on the rearing of summer chinook fry (Oncorhynchus tshawytscha) at the Puntledge Hatchery. Can. Tech, Rep. Fish. Aquat. Sci., No, 1390. Vancouver, British Columbia, Canada.

TGP in the range of 104 - 106% resulted in a small but significant increase in the mortality of summer chinook fry. There were no significant differences in growth between unaerated and aerated treatments, but the fish from the aerated treatments were slightly heavier, relative to their length.

Crustaceans

Brisson, S. 1985. Gas-bubble disease observed in pink shrimp, *Penaeus brusiliensis* and *Penueus Paulensis.* Aquaculture, 47:97-99.

Observations on GBT in marine shrimp. Gas supersaturation was probably due to air entrainment in the water supply.

Amphibians

Colt, J., K. Orwicz and D. Brooks. MS, Gas bubble trauma in the bullfrog *(Ranu catesbeiana)* .

Exposure of adult bullfrog to a AP of 128 mm Hg for 4 days resulted in no mortality, but produced subcutaneous gas bubbles in the webbing and body surfaces, followed by hyperemia, and petechial and ecchymotic hemorrhagtng. When held at a *ΔP of* 67 *mm Hg for 27 days, no clinical signs of gas bubble trauma were observed*

Colt, J., K. Orwicz, and D. Brooks. 1984. Effects of gas-supersaturated water on *Rana catesbeiana* tadpoles. Aquaculture, 38: 127- 136.

Exposure of tadpoles to gas supersaturation for 4 days resulted in accumulation of gas in the *gut and positively buoyant animals. Mortality was increased for exposures longer than 10 days.*

Colt, J,, K. Orwicz, and D. Brooks. 1984. Gas bubble disease in the African clawed frog, *Xenopus* laeuis. J. Herpet., 18:131-137.

Clinical signs of GBT in Xenopus include bubble formation in the webbing of the hind legs and accumulation of *gas in the body cavity, The clinical signs of GBT in thsese animals are similar to "red leg" disease.*

Egusa, S. 1954. Morbidity of the frog due to the oversaturated air in the medium water. Proc. Japan. Acad. (Series B): 30:232-235.

Early description of gas bubble trauma in Rana species.

Orwicz, K. 1985. The effects of gas supersaturation on amphibians. In: Proceedings on the Captive Propagation and Husbandry of Reptiles and Amphibians. R. Gray (ed), Northern Californai Herpetological Society, Davis, California, pp. 153- 162.

A review of gas supersaturation, mechanisms for production, measurement, biological effects, and removal of gas supersaturation,

Orwicz, K. and J. Colt. 1986. Prevention of gas bubble trauma in captive amphibians. In: Ninth International Symposium on the Captive Breeding and Husbandry of Reptiles and Amphibians. S. McKeown, F. Caporaso and K. H. Peterson, (eds). Zoological Consortium, San Diego, California, pp.81-99.

A review *of* the design *of* amphibians holding and culture systems to prevent gas' bubble trauma.

Mollusks

Elston, R. 1983. Histopathology of oxygen intoxication in the juvenile red abalone, Haliotis *refescens* Swainson. J. Fish Dis,, 6: lOl- 110.

Histopathology of GBT resulting form high dtssolved oxygen,

Others

Hemmingsen, E. A. 1982. Cinephotomicrographic observations on intracellular bubble formation in *Tetrahymena.* J. Exp. Zool., 220:43-48.

GBT in the protozoan Tetrahymena.

Hemmingsen, B. B. and E, A. Hemmingsen. 1983. Intracellular bubble formation: fiferences in gas supersaturation tolerance between *Tetrahymena* and *Euglena,* J, Protozool., 30:609-612.

Cells of Tetrahymena pyrtformts, T. thermophila, and Euglena gracis were saturated with *nitrogen gas at pressures up to 300 atm and rapidly decompressed. The extreme gas supersaturations induced, led to intracellular bubble formatton and rupture in cells of Tetrahymena that contained food vacuoles, but only with supersaturations* of *175 atm or higher; 225 atm left few cells intact, Bubbles* were *never observed in cell of Euglena or in Tetrahymena* cells *freed of food* vacuoles, even *when they were decompressed from substantially higher nitrogen supersaturattons. Cells of Euglena were most resistant and* were *unaffected by supersaturations up to 250 atm.*

ECOLOGICAL IMPACTS

Streams and Rivers

Alderdice, D, F. and J. 0. T. Jensen. 1985. Assessment of the influence of gas supersaturation on salmonids in the Mechako River in relation to Kemano Completion. Can. Tech. Report Fish, Aquat. Sci., No. 1386.

TGP should be maintained below 104 - 105 % to prevent chronic GBT in streams.

Berg, A, et al. 1984. Supersaturation of dissolved air in the waterways of hydroelectric power plants: causal relationships, detrimental effects and preventive measures, Norwegian Hydrodynamic Laboratories.

Colt, J. 1984. Seasonal changes in dissolved-gas supersaturation in the Sacramento River and possible effects on striped bass. Trans, Am, Fish. Soc. 113:655-665,

Gus supersaturation in the American *and Sacramento Rivers may have a signficant effect on hatchery reared salmonids and wild striped bass larvae. The source of this gas supersaturation muy be natural, but the presence of*large dams increases the duration of high levels of gas supersaturation.*

Hauck, K. 1986, Gas bubble disease due to helicopter transport of pink salmon. Trans. Am. Fish. Soc., 115:630-635.

Reduced atmospheric pressure during helicopter transport *can* result in serfous gus bubble *trauma, Hyperinflation* ***of*** *the swimbladder* appears *due to the expansion* ***of*** *the gases contained* in the swimbladder rather *than to transfer of gases into* the *swimbladder. Exophthalmos, cranial swelling, edematous and swollen gill lamellae, hemoperitoneum, gas bubbles within the* yolk *sac, and distention und rupture* of *the* yolk *sac membrune were also observed.*

Heggberget, T. G. 1984, Effect of supersaturated water on fish in river Nidelva, southern Norway. J. Fish Biol., 24:65-74.

Diversion ***of*** *water* pass *the power station on the Nidelva River resulted in very high levels of gas supersaturation and fish mortality from GEW.*

White, R. G,, G. Phillips, G. Liknes, S. Sanford. 1986. The effects of supersaturation of dissolved gases on the fishery of the Bjghorn River Downstream of the Yellowtail Dam. 1985 Annual Report, Bureau of Reclamation, Missouri Basin, Montana Cooperative Fisheries Research Unit, Montana State University, Bozeman, Montana, 62.P

Sluice-gate apenings are more closely correlated with total gas pressure than any other parameter considered, while radical gate openings Were *megatively* correlated. Higher saturation levels *on the sluiceway side are reflected by a higher incidence of gus bubble trauma in fish* collected from that *side* of *the* ***river.*** Future adjustment *in* the *proportion of discharge from radial and sluice-gate could lower supersaturation levels and benefit the fishery.*

Lakes

Mathias, J. A. and J. Barica. 1985. Gas supersaturation as a cause of early spring mortality of stocked trout. Can. J. Fish. Aquat. Sci., 42:268-279,

As water freezes, *the dissolved gases are quantitatively forced into the remaining water. During the spring, lethal levels of gas supersaturation may be present in shallow "prairie lakes" even though the dissolved oxygen is high Nsh can not be stocked in these lake until the ice has completely melted and the lake has re-equilibrated,*

Oceans and Bays

Fairbanks, R. B. and R. P. Lawton. 1977. Occurrence of large striped mullet, *Mugil cephalus,* in Cape Cod Bay, Massachusetts, Chesapeake Sci., l&369-310,

Total gas pressure in the discharge ***of*** *Pilgrim Nucleur Generating Station in December was 114.9' %. Sixty percent* ***of*** *the striped mullet exhibited subcutaneous emphysema between the fin rays.*

Reintjes, J. W, 1969. Synopsis of biological data on the Atlantic menhaden, *Brevoortia tyrannus.* Circular 320, US. Fish and Wildlife Service.

Gus emboli *and exophthalmia were observed in menhaden during period of muss mortality in the* Chesapeake Buy.

[Mass mortality ***of*** *menhaden may be due to gas bubble trauma resulting from natural heating.]*

Westman, J. R, and R, F. Nigrelli, 1955. Preliminary studies of menhaden and their mass mortality in Long Island and New Jersey waters. New York Fish Game J., 2:142-153.

Gas emboli and exophthalmia were observed in menhaden during period of mass mortality in the Long Island Sound and New Jersey waters.

[Mass mortality of menhaden may be due to gas bubble trauma resulting from natural heating.1

Zaitsev, Y. P. 197 1. Marine Neustonology. Israel Program for Scientific Translations+ Jerusalem,

The development of a large elongated air bubble on the backs of striped and long-finned mullet was thought to be an "accessory hydeostatioc device", and has been observed in the Black'Sea, Central America, and the South pacific,

[These bubbles may have results from high levels of gas supersaturation in the surface zone during calm conditions.]

Aquaculture Ponds

Parker, N. C., M. A. Suttle, and K. Fitzmayer. Total gas pressure and oxygen and nitrogen saturation in warmwater ponds aerated with airlift pumps. Aquacult, Eng., 3:91-102.

The operation of air-lift pumps in striped bass ponds does not increase the levels of gas supersaturation. No evidence of GBT was found,

Takashi, I. and S. Yoshihiro. 1975. Productivity in fish culturing ponds. In: Productivity of communities in Japanese waters, S, Mori and G. Yamamoto (eds .), Japanese Committee for the International Biological Program, ' Vol. 10, University of Tokyo, Japan, PP.237-86.

Photosynthesis and solar heating can produce APO2 values up to 450 mm Hg, resulting in almost complete mortality of goldfik

PRODUCTION OF GAS SUPERSATURATION

Heating

Bouck, G. 1984. Annual variation of, gas supersaturation in four spring-fed Oregon streams. Prog. Fish-Cult., 46: 139- 140.

Spring fed streams in Oregon showed strongly seasonal variation in gas supersaturation. The maximum AP occurred during May to September,

Ice Formation

Mathias, J. A. and J, Barica. 1985. Gas supersaturation as a cause of early spring mortality of stocked trout, Can. J. Fish. Aquat. Sci., 42:268-279.

*As water freezes, the dfssolved gases **are** quantitatively forced into the remaining water. During the spring, lethal levels of gas supersaturation may be present in shallow 'prairie lakes" even though the dissolved oxygen fs high,*

Air Entrainment land Spill Modelling

Chan, J, G, and Q. D. Shephen-Hassard, X977. A fish kill in Hawaii caused by gas-bubble disease. Fish Health News, 6: 186-188.

Inadequate pump submergence during low tide was apparently responsfble for production of gas supersaturation in shallow ponds. Surface heating of the water may have also contributed,

Colt, J. and H. Westers. 1982. Production of gas supersaturation by aeration. Trans. Am. Fish. Soc., 111:342-360.

Highly eficient submerged aerators can result in lethal levels of gas supersaturation

Kils, U. 1976/1977, The salinity effect on aeration in mariculture. Meeresforsch., 25: 755-759.

The rate of dissolution of air appears to be approximately 10 times higher in seawater than in freshwater.

ISmall air leaks in a marine system may result in high levels of gas supersaturation and be difficult to detect as no bubbles m&y be present in the discharged water].

Johnson, P. L. and D, L. King. 1979. Prediction of dissolved gas at hydraulic structures. In Symposium on Reaeration Research, American Society of Civil Engineers, New York, pp 76-90.

Based on the two-film model, a mass transfer model was developedfor gas transfer at dams.

USACE [United States Army Corps of Engineers]. 1986. Gasspill: system spill allocation model for the control of dissolved gas supersaturation in the Columbia River basin. Water Management Branch, Water Section, North Pacific Division, U. S. Army Corps of Engineers, Portland.

*A model was developed to aid in the scheduling of spill and power generatfng **operations on** the Columbia and Snake Rivers to meet both power generation and dissolved nitrogen criteria. This is a modifiation of the dfssolved nitrogen simulation model developed by WRE in **1971.***

Pressure Changes

Feathers, M. G. and A. E. Knable. 1983. Effects of depressurization upon largemouth bass. North Am. J. Fish. Man., 3:86-90.

*Depressurization can result in over-inflation **of** the swfmbladder and bubbles in the blood.*

Hauck, K. 1986. Gas bubble disease due to helicopter transport of pink salmon. Trans. Am. Fish. Soc., 115:630-635,

Reduced atmospheric pressure during helicopter transport can result in serious gas bubble trauma.

Algae and Bacteria

Callman, J. L. and J. M. Macy. 1984. The predominate anaerobe from the spiral intestine of hatchery-raised sturgeon *(Acipenser transmontanus)*, a new *Bacteroides* species, Arch. Microbial., 140:57-65,

A hydrogen producing anaerobic bacteria was isolated from the gut of the white sturgeon,

[Under some conditions, accumulation of hyfrogen *gas* in the gut resulted in posftfuely buoyant fish).

Kraul, S, 1983. Results and hypotheses. for the propagation of the grey mullet, *Mugil cephalus* L. Aquaculture, 303273-284.

Photosynthetic production of oxygen by algae in 'greenwater" culture may result in GBT in larval mullet.

Physiological Processes

Dehadrai, P. V. 1966, Mechanisms of gaseous exophthalmia in the Atlantic cod, *Gadus morhua* L. J. Fish. Res. Bd. Canada, 23:909-914.

Cod may develop exophthalmfa when held in saturated water due to malfunctioning of the choroid gland-pseudobranch complex.

[No information on dfssolved gas levels given.]

Engelman, R. W., L. L. Collier, and J. B. Marliave. 1984. Unilateral exophthalmos in *Sebastes* spp.: histopathologic lesions. J. Fish. Dis., **73467-476.**

Spontaneous unilateral exophthalmos *occurs i give species* of *rockfish [Sebastes) held in aquaria. Bubble formation in the choroidal rete mfrabile was one of several possible mechanisms discussed.*

. [Dissolved gas levels were not measured.]

Fange, R. 1983. Gas exchange in fish swim bladder. Rev. Physiol. Biochem. Pharmacol., 97: 11258.

Review of the rete mfrabile of the swim bZadder,and eyeThese organs may produce very high oxygen partial pressures due *to a* countercurrent *gas exchange mechanism*

Kolbeinshavn, A, and J. C. Wallace. 1985. Observations on swim bladder stress syndrome in arctic charr *(Saluelinus alpinus),* induced by inadequate water depth. Aquaculture, 36:259-261.

Increasing *the water depth from 12* cm *to 37 cm dignificantly decreased the incidence* ***of*** *over-inflated swim bladders (Swim bladder stress syndrome).*

[Swim bladder stress syndrome may be related to inadequate hydrostatic compensation)

General

Colt, J. and K. Orwicz. In Press, Impact of water source, treatment, and distribution on gas supersaturation in municipal water supplies. Aquacultural Engineering,

The seasonal variation in dfssolved gases were monitored in systems using groundwater and surface waters. Groundwaters were typically more highly supersaturated than surface waters, but may depend on the characteristics of the recharge area and hydrology.

Colt, J. 1986. The impact of gas supersaturation on the design and operation of aquatic culture systems. Aquacult. Eng., 5:4<3-86.

Review of the mechanism of production of gas supersaturation, seasonal variation of gas supersaturation in different environments, and prevention **of** *GBT in aquatic systems.*

MONITORING AND REPORTING

Histological Techniques

Bell, T, G., A. L. Trapp, J. P. Machado, and D. L, Garling, Jr. 1985. A method for rapid fixation for preservation of tissue emphysema: diagnosis of gas bubble disease in hatchery reared rainbow trout. Amer. Assn. Vet. Lab. Diag., 28:81-85.

Fixation ***for*** *10 minutes with Boufn's solution at 48 C was found to be superior* ***for*** the *preservation* ***of*** *tfssue emphysema resulting from gas supersaturation.*

Dissolved Gas Levels

Benson, B. B. and D. Krause. 1984. The concentration and isotopic fractionation of oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere. Limn. Ocean., 29:620-632.

The most accurate solubility data ***for*** *oxygen in freshwater* and *seawater.*

[This information is needed ***for*** *the computation* ***of*** *some gas supersaturation parameters.]*

Bouck, G. R. 1982. Gasometer: an inexpensive device for continuous monitoring of dissolved gases and supersaturation. Trans. Am. Fish. Soc., 111:505-516.

Description and operation ***of a*** *membrane-diffusion device* ***for*** *measurement* ***of*** *ΔP. This unit is ideal for fixed site monitoring* ***of*** *influent* waters *as it can be installed in pipes*

Colt, J. E, 1983. The computation and reporting of dissolved gas levels. Wat. Res., 17841-849.

Recommends standards ***for*** *the computation and reporting* ***of*** *gas supersaturation parameters.*

Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure. Special Publication No. 14, American Fisheries Society, Bethesda, Maryland,

Detailed information on the solubility ***of*** *oxygen, nitrogen, argon, and carbon dioxide in freshwater and* ***seawater.*** *Example problems and computer programs are included* ***for*** *HP-41 CVs.*

Dawson, D. K. 1986. Computer program calculation of gas supersaturation in water. Prog. Fish-Cult,, 48: 142-146,

A *short computer program* ***for*** *computation* ***of gas*** *supersaturation* ***parameters.*** Written *in* BASIC ***for the*** *Apple He or IBM PC, but can be modified to run on most other microcomputers.*

Perie, W. R. and W. A. Hubert. 1977. Assumptions in statistical analysis.. Trans. Am. Fish. Soc., 106:646-648,

Thfs *paper* analyzes the statistical distribution of the data present by Fickeisen, D. H., M. J. *Schneider, and J, C. Montgomery. 1975. A comparative evaluation* ***of*** *the Weiss saturometer. Trans. Am. Fish; Soc., 104:816-820.*

The paired-t test used by Fickeisen et al., was inappropriate, and there is a statistical difference *between the Weiss saturometer and the gas chromatography methods* ***of*** *gas analysis. These two methods* measure *two fundalmentally different parameters and the lack* ***of*** *similarity does not invalidate either method.*

DEGASSING

Packed Columns

Bouck, G. R,, R. E. King, and G. Bouck-Schmidt. 1984. Comparative removal of gas supersaturation by plunges, screens and packed columns, Aquacult, Eng,, 3:159-176.

Packed columns are the most efficient method for degassing,

Colt, J. and G. Bouck. 1984. Design of packed columns for degassing, Aquacult. Eng., 3:251-273.

Based on published mass transfer models for the packed column, detailed information is presented on the operational characteristics for degassing as a function of environmental and operating conditions.

Dawson, V, K. and L. L. Marking. In Press, Performance of an integrated system for treating gas supersaturated water. Prog. Fish-Cult.

Hackney, G. and J. E. Colt. 1982. The performance and design of packed column aeration systems for aquaculture. Aquacult. Eng., 1:275-295.

Development of a mass transfer model for the packed column aerator based on experimental work.

Marking, L. L,, V. K. Dawson, and J. R, Crowther. 1983. Comparison of column aerators and a vacuum degasser for treating supersaturated culture water. Prog. Fish-Cult., 45:81-83.

In waters containing low dissolved oxygen, the use of vacuum degassing may result in dissolved oxygen concentration too low to be used for fish culture. Under these conditions, it may be necessary to first pass the water through a packed column to increase the dissolved oxygen.

McLean, W. E. and A. L. Boreham, 1980. The design and assessment of aeration towers. Fisheries and Oceans, Vancouver, British Columbia, Canada (unpublished).

Presents detailed information on the performance and design of packed columns.

Owsley, D, E. 1981, Nitrogen removal using packed columns. In Proceedings of the Bio-engineering Symposium for Fish Culture, Eds., L. J. Allen and E. C. Kinney, Fish Culture Section, American Fihseries Society, Bethesda, Maryland, pp. 71-82.

Design of packed columns for degassing.

Vacuum Systems

Colt, J. and G. Bouck, 1984. Design of packed columns for degassing. Aquacult. Eng,, 3:251-273.

A mass transfer model for vacuum packed ***is developed and operational limitations are*** presented

Dawson, V. K. and L, L, Marking, In Press, Performance of an integrated system for treating gas supersaturated water, Prog. Fish-Cult,

Fuss, J. T. 1983, Effective flow-through vacuum degasser for fish hatcheries. Aquacult. Eng., 2:301-307.

Performance ***and design information for a small vacuum packed column,***

Fuss, J. T. 1986. Design and application of vacuum degassers. Prog. Fish-Cult., 48:215-221,

Practical design information an a number of full-scale vacuum degassing systems.

Marking, L. L., V. K, Dawson, and J. R. Crowther, 1983, Comparison of column aerators and a vacuum degasser for treating supersaturated culture water. Prog. Fish-Cult., 48~81-83.

In waters containing low dissolved oxygen, the use ***of vacuum degassing may*** result ***in dissolved oxygen concentration too low to be used for*** fish ***culture. Under these conditions, it*** may be ***necessary to first pass the*** water through ***a*** packed column ***to increase the dissolved oxygen.***

Screen Decks

Hartman, J. 1983, Performance and operation of Alaska Department of Fish and Game screen decks, In: Gas supersaturation in hatcheries - caused, effects, and solutions, Bio-engineering Sections, American Fisheries Society, Milwaukee, Wisconsin, pp. 9-l to 9-7 (unpublished).

Under ***conditons of high solids loading and leaf fall, clogging may*** be a ***serious*** problem in ***packed columns. Horizontal screens*** can ***be used under these conditions, The individual screens can be removed and cleaned while the unit is operating.***

McLean, W, E, and A. L. Boreham. 1980. The design and assessment of aeration towers, Fisheries and Oceans, Vancouver, British Columbia, Canada (unpublished).

Presents information on the performance and design of aeration towers.

CURRENT RESEARCH

Alderdice, Don

Impact of hydro-power development on gas supersaturation in the Nechako River System.

Armstrong, Gary

Monitoring of gas supersaturation in hatcheries.

Beck, Todd

Monitoring and degassing of power plant effluent, Application of hydraulic ram pump applications for oxygenation and degassing,

Bell, Thomas

Impact of gas supersaturation on blood physiology.

Boon, J. H.

Gas bubble disease in young Clarion gariepinus.

Bouck, Gerald

Development of standards for the measurement and reporting of gas supersaturation.

Busch, Robert

Effects of chronic low levels of gas supersaturation on the survival and growth of early life stages of rainbow trout,

Cochran, James

Monitoring of dissolved gas levels and effects on salmonids,

Colt, John

Development of standards for the measurement and reporting of gas supersaturation. Variation of dissolved gas levels in surface and groundwaters. Effects of chronic exposure to low levels of gas supersaturation on fish and amphibians.

Commonwealth Scientific

Improved methods of dissolved gas analysis,

Corman, Richard

Improvements in measurement techniques for total dissolved gas pressure

D'Aoust, Brian

Development of monitoring equipment for gas supersaturation measurements.

Driver, John

Use of packed columns and pure oxygen to reduce gas supersaturation in production hatcheries. The Use of Xobox oxygen generation systems.

Fariano, Alberto

Design of degassing systems

Ferber, Larry

Degassing techiques for production hatcheries.

Fidler, Larry

Experimental and mathematical determination of the physiological parameters which govern bubble growth in the vascular systems of fish exposed to supersaturated water.

Frantsi, Chris

Design of degassing columns for production Altantic salmon hatcheries.

Garling, Donald

Design of degassing systems. Impact of gas supersaturation on blood physiology,

Ginot, Vincent

Modelling oxygen dynamics in pond ecosystems.

Gleim, Jim

The use of packed column degasser and oxygen injection. Weekly monitoring of gas levels before and after treatment.

Heggberget, Tor

Ecological impact of gas supersaturation from hydroelectric power plants.

Hnath, John

The effects of nitrogen gas supersaturation and diet on eye lesions of coho salmon.

Horner, Rodney

Production of gas supersaturation by ice formation.

Jensen, John

Impact of gas supersaturation on salmonid eggs, alevins, and fry. Modelling of the response of salmonids to gas supersaturation.

Katavic, Ivan

Impact of gas supersaturation on striped bass.

Kayes, Terry

Assessment of low-level gas supersaturation as a stressor in lake trout and rainbow trout.

Krise, William

Long-term effects of gas supersaturation on Atlantic salmon and Lake ,trout. Histology of gas bubble trauma. Acute gas ‘bubble trauma, effects on Atlantic salmon and lake trout. Effects of gas supersaturation on feeding and growth.

Kuhlmann, H.

Importance of dissolved gases for fishes.

Landye, Jerry

Gas supersaturation at Canyon Creek State Fish Hatchery.

Leclercq, Didier

Degassing of power plant effluent.

Marking, Lief

Evaluation of available degassing systems.

Marshall, Bruce

Design of degassing columns.

Mason, Mike

Degassing and reaeration of surface water supply.

McInerny, Michael

Field work on gas-bubble disease in the heated effluent of steam-electric plant,

McLean, Bill

Bubble formation in Heath Tray incubators at Rob Hatchery,

McMullen, John

Impact of gas supersaturation on abalone,

Mohr, Anfreas

Physiological and biochemical effects of normobaric hyperoxie on rainbow trout.

Mudrak, Vincent

Evaluation of (1) various types of gasometers and (2) portable 'vacuum degasser,

Orwicz, Kris

Effects of gas supersaturation on amphibians. Production of gas supersaturation.

Prickett, Richard

Effects of gas supersaturation on swim bladder inflation.

Schachte, John

Measurement of chronic sublethal effects of nitrogen supersaturation in brook trout. Evauluation of a computerized water quality monitoring device for nitrogen supersaturation.

Schweinforth, Ross

Chronic effects of gas supersaturation on channel catfish fingerlings.

Shrimpton, Mark

Experimental evaluation of physiological parameters that govern the overinflation of swim bladders in fish exposed to supersaturated water.

Smith, Charlie

Effects gas supersaturation on various life stages of lake trout, brown trout, and rainbow trout.

Varela, Maria

Effects of gas supersaturation on fish during transport.

Wegner, Dave

Monitoring and review of water quality data on the Colorado River.

Westers, Harry

Application of oxygen generators to control dissolved gases.

White, Robert

Effects of supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail Afterbay Dam, Montana.

ARGENTLA
Luchini, Laura

AUSTRALIA
Thomsett, P.J.

AUSTRIA
Adam, Hans
DalIaria, J,

BELGIUM
Dervichian, Andre

BRAZIL
Brisson, S.
Vieira, Liana

CANADA
Alderdice, Don
Andrews, Fred
Boreham, Alan
Carson, D. E.
Clark, Malcolm J. R.
Core, C.
Corey, Lee
Corman, Richard
Couturier, Cyr
Drouin, Maurice
Durant, Gordon ,
Farmer, G.
Fidler, Larry
Frantsi, Chris
Garrett, Kim
Gots, B. L,
Hamor, Thomas
Harding, David
Hebinger, C.
Hilbein, C. J.
Hulsman, Peter
Jensen, John
Johnson, Keith
Johnson, Edward
Johnson, Bob
Judson, Irwin
Kiceniuk, Joe
Legault, Michel
Lill, A. F.
Loftus. Kevin
MacDonald, Don
Mathias, Jack
MCI ean, Bill
Neima, Paul
Orvis, G. E.
Ostland, Vaughn
Parke, Clyde
Petersen, K.
Richard, Peter

CANADA
Saunders, ,Richard
Sawchyn, W. W.
Scales, Peter
Shepherd, Bruce
Shrimpton, Mark
Smith, J.
Wort, D. E.
Yoshida, Howie

CZECHOSLOVAKIA
Knoteli, Z.
Pialek, Jaroslav

EAST GERMANY
Grahl, K.
Seidel, B.

ENGLAND
Clarke, J. N.
Gillespie, M. J. $,
Ingram, M. V,
Johnstone, Alastair
Prickett, Richard

FINLAND
Jarvisalo, Otso

FRANCE
Billard, Roland
Dumon, Henri
Elie, P.
Gabauden, J,
Ginot, Vincent
Hollebecq
Kentouri, M.
Leclercq, Didier
Neveu, A
Person-le Ruyet, J.
Primet, Paule

GREECE
Varela, Maria

HUNGARY
Csaba, G.

ICELAND
Petursson, Robert

INDIA
Kulshrestha, ;A. K.
Mandal, P. K.

IRELAND
Broderick, Alan

ISRAEL
Avnimelech, Yora
Galman,O.
Koiller, Marcos
Porter, Cohn
Sarig, s.

ITALY
Fariano, Alberto
Scarano, G.

KUWAIT
Hopkins, Kevin
Hussain, N.

MEXICO
Aguilar, L. J.

NETHERLANDS
Boon, J. H.
Merman, E. A.

NORWAY
Heggberget, Tor
Herikstad, Hallgeir
Jobbing, Malcolm
Killie, Jan-Eirik
Kittelsen, Arne
Kolbeinshavn, Arne
Skogkeim, Odd K.
Vassvik, Vidar

PANAMA
Kaelin, Andrew .
Pang, Jorge

PERU
Huanay, Elena

PHILIPPINES
Juario, Jess
Pauly, Daniel
Posadas, R A
Pullin, Roger

POLAND
Opuszynski,m Karol
Stanislawski, Wlodzimierz

SCOTLAND
Beveridge, M. C. M.
Gllespie. Malcolm
Linfoot , Brian
Mann, A. G
Muir. John
Murray, Keith
Phillips, M. T.
Poxton, M. G.
Varela, Maria

SINGAFORE
Cheong, Leslie

SOUTH KOREA
Kim. In-Bae

SPAIN
Morales, Jesus
Ramos, P.
Vidaurreta, A,

TAIWAN
LIU, F.

UNITED STATES
Ables, Ernest
Adams, Gary
Allee, Brian
Anderl, D. M.
Anderson, Dennis
Anderson, Richard
Anderson, Richard
Armstrong, Gary
Avault, James
Barnhart, Gerald
Bathel, Darryl
Beck, Allan
Beck, Todd
Becker, Dale
Beer, Ken
Beiningen, Kirk
Bell, T,
Bell, Thomas
Bengston, Cl@
Binkowski, Fred
Bishop, Harry
Blank, Dud
Blasiola, George
Boersen, Gary
Bouck, Jerry
Brandenburg, Alan
Brown, Steven
Burtle, Gary
Busch, Robert
Busch, R L.
Camenisch, Gary
Casian, J. A.
Castagne, Michael
Caufield, Jim
Ceasla, Zacatias
Cech, Joe
Chamberlain, George
Chapman, Gary
Clemens, Kathy
Clfne, Kenneth
Cochran, Lincoln
Cochran, James
Cochran, Mike
Colt, John
Conte, Fred
Cook, Peter
Cordes, Rick

UNITED **STATES**
Couch, Bill
Coutant, Charles
Coykendall, Robert
Crawford, Tommie
Crees, Ronald
Cremer, Mike
Cross, Verlin
Crunkilton, R L.
Curry, Charles
Czarnizki, J. M,
D'Aoust , Brian
Daley, Wayne
Dawson, V. K.
Dinnel, Paul
Dorman, Larry
Doroshov, Serge
Dotson, Thurson
Driver, John
Dupree, Harry
Dwyer, Pat
Elston, Ralph
Estes, Chris
Eubanks, Warren
Ever-sole, A. G.
Fast, Arlo
Ferber, Larry
Fernandez, Renita
Fickeisen, Duane
Focht, Rick
Foltz, Jeffrey
Frazar, Ed
Frey, Paul
Fridley, R. B.
Fuss,Joe
Garlfng, Donald
Gaston, P.
Geiger, James
Gillette, Ken
Gleason, Gale
Gleim, Jim
Gosby, William
Godfriaux, Bruce
Gould, Roland
Grant, Blake .
Greer, E.
Hammond, Jack
Hankins, Joseph
Hanks, Ken
Hanson, D.
Harris, Larry
Harris, Gail
Harttnan, Jeff
Harvey, James
Hauck, Kent
Hays, J.
Hedrick Ron
Hemmingsen, Barbara
Hemmingsen, Edvard
Hendrix, Michael
Henson, Don
Herr, Chris
Hnath , John
Hood, Shyrl

UNITED STATES
Homer, Rodney
Houk, James
Huber, John
Hughes, Janice
Huguenin, Ted
Janeke, Paul
Jensen, John
Johnson, M.
Johnson, Ken
Johnson, Leigh
Kane, Bill
Kapuscinski, Anne
Katz, Max
Kayes, Terry
Kelly, David
Kepshire, Bernard
Kerns, Curt
Kidder, Jay
Klemetson, Stanley
Klontz, George
Knowles, Michael
Kohler, Chris
Kraeuter, John
Kraul, Syd
Krise, William
Kruckenberg, Wayne
Kubauf, John
Kuntzelman, Don
LaBounty, James
Landye, Jerry
Larkin, Mike
Larson, Douglas
Lee, Linda,
Lewis, Ernest
Li, Hiram
Lientz, Joe
Lightner, Donald
Livingstron, Don
Locke, David
Lundeen, Jim
MacMillan, John
Mandis, Tom
Manthe, Don
Marcino, Joe
Marking, Lief
Marshall, Bruce
Mason, Mike
Massingill, Michael
McCormick, Howard
McCosker, John
McDaniel, David
McGinty, Andrew
McInerny, Michael
McMullen, John
Meams, Alan
Melvin, Edward
Merriman, D, R.
Merritt, Albert
Michaels, Jim
Millard, Jack
Miller, Edward
Mitchum, Douglas
Monaghan, J. P.

UNITED STATES

Monk, Bruce
Moore, Alan
Moors, Alan
Morgan, Kenneth
Mudrak, Vincent
Mulka, Dennis
Mulvihill, Michael
Nebeker, Alan
Nelson, John
Orsborn, John
Orwicz, Kris
Owsley, David
Paeschke, Bob
Parker, Nick
Pasley, Chris
Paust, Brian
Pecor, Charles
Perry, T. D.
Peterson, Paul
Peterson, Gary
Pfister, P. J.
Phillips, Bill
Phillips, Lyndsay
Piper, Bob
Poole, Jane
Powell, David
Powers, Kurt
Proctor, Gordon
Pugh, R W.
Rich, Alice
Richards, John
Ringlw, John
Robmette, Randy
Ryan, Connie
Sandifer, Paul
Schachte, John
Schuur, Tony
Schwedler, T. E.
Schweinforth, Ross
Scrivani, Pete
Shea, Neil
Sheets, W.
Sieswerda, Paul
Simco, Bill
Smith: Charlie
Smith, Lewis
Smith, Theodore
Snyder, K. L.
Soule, Norman
Speece, Robert
Spotte, Stephen
Spykerman, Jerry
Staha, Ron
Steinberg, Nisan
Strawn, Kirk
Stutz-Lumbra, Priscilla
Sullivan, Joseph
Summerflet, Robert
Suppes, Charles
Taylor, Frank
Thayer, Roger
Thorn, Bill
Thursion, Robert

UNITED STATES

tobias, William
Tomasso, Joe
Toole, Christopher
Toth, Robert
Trial, L.
Tucker, Craig
Turner, John
Van De Bogart, Lee
Vande Sande, Ted
Vaughan, Gene
Vernesoni, Michael
Wade, S. E.
Waldvogel, Jim
Wallace, Richard
Warren, James
Watten, Barnaby
Waugh, Godfrey
Wedemeyer, Gary
Wegner, Dave
Weitkamp, Don
Wellborn, Thomas
Wencker, James
West, Graden
Westers, Harry
White, Robert
Wingfield, William
Wolke, R E.
wood, Nancy
woods, Curry
Worcester, Karen
Wulff, Ron
Wyatt, Bruce

WALES

Wickins, J. F.

WEST GERMANY

Deufel, J.
Hilge, V.
Hofer, Peter
Keesen, Heinz
Kinne, Otto
Kuhlmann, H.
Mohr, Andreas
Quantz, Gerrit
Rosenthal, H.
Stippl, Stefan

YUGOSLAVIA

Katavic Ivan

NAMES AND ADDRESSES

To increase communication between between interested parties in the field of gas supersaturation research and control, address and telephone numbers of all people responding- to the questionnaire are included in this section, The last item for each individual is a code for their areas of interest:

a: Ecological Impacts

b: Bubble Formation

c: Gas Bubble Trauma (Gas Bubble Disease)

d: Supersaturation/Spill Modeling

e: Gas Measurement

f: Degassing

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